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A Validated Visual Decision-Support Tool for Inferential Statistical Test Selection: The Velarde-Camaqui Diagram

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***Abstract*–** Selecting an appropriate statistical test remains a persistent challenge for students and novice researchers, as it requires coordinating multiple methodological conditions and decision criteria. Existing visual tools often provide direct recommendations but do not make the underlying decision pathway explicit and frequently lack empirical validation. This study presents the development and expert validation of the Velarde-Camaqui Diagram, a visual decision-support tool designed to guide users through inferential statistical test selection using a structured, sequential approach. A mixed-methods design was conducted with 14 PhD-level experts in education and statistics. Results showed high agreement across clarity, coherence, relevance, and usability (85–100%). Content validity was supported by an overall Aiken's V of .89. Qualitative findings highlighted strengths in conceptual clarity and pedagogical usability, while identifying opportunities for improving visual structure. The diagram contributes by making the inferential decision process explicit, integrating both parametric and non-parametric tests, and offering a multilingual, accessible format. These features position it as both a decision-support system and a pedagogical scaffold. Future research should examine its impact on learning outcomes and statistical decision-making in applied contexts.

Keywords-- graphic organizers, statistics, research pedagogy, educational innovation, higher education, decision-support tool, engineering education

I. Introduction

The process of selecting an appropriate statistical test is one of the most frequent yet complex decisions researchers face during data analysis. Students and novice researchers often encounter difficulties determining which test corresponds to their data type, hypothesis, and research design [1]. The challenge extends beyond mathematical knowledge; it involves conceptual understanding and cognitive decision-making under uncertainty. As a result, inappropriate test selection can produce misleading conclusions, limit reproducibility, and compromise the validity of empirical findings [2], [3].

Previous research has identified two major barriers to this learning process. The first is **cognitive complexity**: statistical reasoning requires connecting multiple variables, conditions, and assumptions, which imposes a heavy cognitive load on learners [4], [5]. The second is **statistical anxiety**, a psychological phenomenon that interferes with students' confidence, performance, and engagement when confronted with quantitative reasoning tasks [6], [7]. Together, these barriers explain why many students experience frustration or avoidance when required to perform data analysis [8], [9].

To address these challenges, visual and structured tools—such as flowcharts and decision diagrams—have emerged as effective strategies to scaffold the reasoning required for statistical test selection [10], [11]. These tools break down the analytical process into sequential decisions based on simple questions (e.g., number of groups, variable type, independence), allowing users to follow a logical path rather than memorizing complex statistical rules.

The *Velarde-Camaqui Diagram* was designed to formalize and validate this pedagogical strategy. Developed initially as a prototype in six languages—English, Spanish, Portuguese, Mandarin Chinese, Russian, and French—it aims to democratize access to statistical reasoning through visual guidance. The present study focuses on its expert validation, representing the first methodological stage prior to user-based testing.

This research pursued two objectives:

- To assess the clarity, coherence, relevance, and usability of the *Velarde-Camaqui Diagram* using expert judgment.
- To identify areas for improvement that would strengthen its structure before implementing user validation with students and educators.

Despite the availability of visual tools for statistical test selection, most lack empirical validation, do not make the decision pathway explicit, and remain limited in terms of accessibility and pedagogical design. These limitations reduce their effectiveness as learning supports for novice users. To address these gaps, this study proposes and validates the Velarde-Camaqui Diagram, a structured and multilingual visual decision-support tool. Grounded in cognitive load theory and principles of visual learning, the diagram aims to support statistical reasoning by making the inferential decision process explicit and accessible. By validating the diagram through expert analysis, this work contributes to educational

***Supplementary materials, including all diagram versions, are available at: https://bit.ly/VCDiagrams**

innovation and provides a foundation for subsequent empirical testing in real learning environments.

II. Theoretical Background

A. Cognitive Load Theory and Visual Processing

Cognitive Load Theory (CLT) provides a robust framework for understanding how learners process complex information. According to Sweller [5], working memory has limited capacity; when instructional materials overload this capacity, comprehension and learning efficiency decline. Organizing information into visual or hierarchical structures—such as diagrams or flowcharts—helps reduce extraneous cognitive load by presenting relationships between elements in a concise and interpretable form [12], [13].

In the context of statistics education, diagrams facilitate understanding by enabling learners to visualize abstract concepts, such as relationships between variables or the logic behind hypothesis testing [14]. Visual sequencing also promotes *schema automation*, allowing students to internalize decision patterns and apply them to new analytical contexts [15].

Research supports the notion that visual representations significantly enhance retention and transfer of knowledge. Katona [4] demonstrated through eye-tracking analyses that visual scaffolds improve attention allocation and reduce working-memory overload during algorithmic problem solving. Similar results have been reported in educational settings where flowcharts and mind maps were introduced to teach procedural reasoning [11], [16].

The *Velarde-Camaqui Diagram* aligns with CLT principles by translating abstract statistical reasoning into a visual decision tree. Each node represents a question that leads users toward the correct test through guided logic—thereby minimizing unnecessary cognitive load and helping novices manage complex decision-making without advanced mathematical training.

B. Statistical Anxiety and Learning Barriers

Statistical anxiety, defined as the emotional tension experienced when confronted with statistical content or evaluation, has been extensively documented as a barrier to learning [6], [17]. It negatively affects motivation, self-efficacy, and performance [7]. Leppma and Darrah [18] found that anxiety is particularly acute among students in non-mathematical disciplines, where statistical reasoning is perceived as abstract or irrelevant.

Anxiety's cognitive effects include reduced working memory and diminished attention, both of which impair the ability to integrate conceptual knowledge with procedural reasoning. These findings align with the cognitive-affective model of learning, which posits that emotional interference reduces the learner's capacity to perform higher-order cognitive tasks [19].

Pedagogical interventions targeting anxiety often emphasize visual organization and guided sequencing. Flowcharts, for example, externalize decision processes, providing a tangible representation of reasoning steps that reduce uncertainty [20], [21]. This external support enables students to focus on conceptual understanding rather than procedural memorization. The *Velarde-Camaqui Diagram* builds upon these principles by presenting a visual map that guides users through logical choices, from defining variable types to identifying appropriate inferential tests.

C. Graphic Organizers as Pedagogical Innovation

Graphic organizers have long been recognized as effective scaffolds for structuring knowledge and guiding reasoning in educational contexts. They transform complex abstract information into visual formats that are easier to interpret and recall [22]. In mathematics and statistics education, this approach has proven particularly valuable for promoting step-by-step analytical thinking and conceptual retention [23], [24].

Flowcharts and diagrams help learners visualize procedural sequences—such as hypothesis formulation, assumption verification, and test selection—thereby clarifying the logical relationships among statistical techniques [10]. Empirical evidence indicates that students who employ graphic organizers outperform peers relying solely on textual or formula-based learning because visuals reduce intrinsic cognitive load and improve metacognitive monitoring.

Diagrams also encourage learner autonomy. Rather than depending exclusively on instructors, students can independently follow a structured path toward correct statistical reasoning [25]. This aligns with contemporary constructivist approaches emphasizing self-regulated learning and visual literacy. By integrating decision rules, the *Velarde-Camaqui Diagram* operationalizes these principles, allowing users to navigate inferential logic through a guided decision map.

The Velarde-Camaqui Diagram extends prior visual tools for statistical test selection by addressing several key limitations. Existing resources, such as statsflowchart.co.uk [26], typically provide a sequence of questions leading directly to a recommended test but do not make the underlying decision pathway explicit, limiting users' ability to understand the reasoning process. Additionally, these tools often focus on more complex multivariate analyses (e.g., MANOVA, MANCOVA) and may omit commonly used non-parametric or correlational tests such as Spearman's rho or Kendall's tau, which are essential for novice learners.

Similarly, guideline-based resources such as the UCLA Statistical Methods and Data Analytics [27] table present structured mappings between variable types and statistical tests; however, they function primarily as static reference tables rather than interactive or sequential decision-support systems. As a result, they do not explicitly guide users through a step-by-step reasoning process.

In contrast, the Velarde-Camaqui Diagram integrates a fully visual and sequential decision pathway that makes the inferential logic explicit, incorporates both parametric and non-parametric tests commonly used in introductory and applied research contexts, and is available in multiple languages. This combination positions the diagram not only as a decision-support tool but also as a pedagogical scaffold that promotes conceptual understanding of statistical reasoning.

III. Methodology

A. *Design*

This study adopted a content validation design based on expert judgment [28], [29]. A mixed-methods approach was used to capture both quantitative consensus and qualitative insight. Quantitative data were obtained through Likert-scale ratings, while open-ended responses provided interpretative depth on perceived strengths and weaknesses.

B. *Participants*

Fourteen experts participated voluntarily after receiving an invitation explaining the study's aims and confidentiality guarantees. Inclusion criteria required a doctoral degree in education, statistics, or related fields, at least ten years of professional experience, and previous authorship or teaching experience in quantitative research methods. The final group consisted of ten experts in educational innovation and four in applied statistics, representing institutions in Latin America, Asia, and Europe. Their mean experience was 20.2 years (SD = 9.54). All participants signed digital informed consent forms in compliance with institutional ethical standards. Each expert evaluated the English version of the diagram individually to avoid group influence or conformity bias.

The panel included experts with combined pedagogical and technical perspectives, including extensive experience teaching quantitative research methods at undergraduate and graduate levels, supervising empirical studies, and supporting statistical decision-making in applied research. This diversity strengthened the relevance of the feedback for both instructional and practical use. To preserve confidentiality, individual demographic details are not reported. Although the sample size was relatively small (n = 14), it aligns with established standards for expert-based content validation studies, where panels typically range between 5 and 20 specialists.

C. *Instrument*

The *Expert Evaluation Questionnaire* contained 12 items divided into four dimensions:

- **Clarity** – the ease with which concepts and decision paths were understood.
- **Coherence** – the logical consistency of the diagram's structure and transitions.
- **Relevance** – the pedagogical and practical significance of the diagram for teaching statistics.
- **Usability** – the perceived applicability and effectiveness for educational contexts.

A 3-point Likert scale was used to reduce central tendency and encourage decisive expert judgments during early-stage validation (1 = Disagree, 2 = Partially Agree, 3 = Totally Agree). Each dimension also included an open comment box for qualitative suggestions.

D. *Procedure*

The validation unfolded in five phases (see Figure 1):

1. **Initial Development** – drafting of the diagram based on inferential decision rules [30].
2. **Expert Review** – distribution of the diagram and questionnaire to experts.
3. **Quantitative Analysis** – calculation of mean scores and acceptance rates.
4. **Qualitative Analysis** – thematic coding of expert feedback.
5. **Refinement** – revision of content and design elements before multilingual translation.

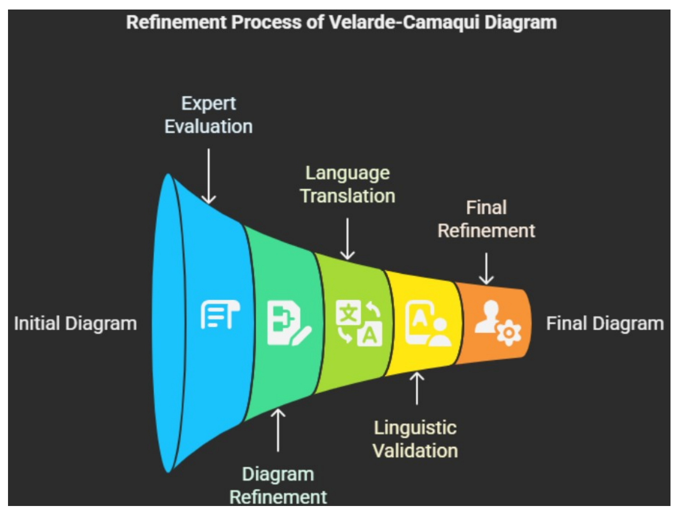

FIG. 1. Process of Velarde-Camaqui Diagram

E. *Data Analysis*

Quantitative data were summarized using descriptive statistics (mean, standard deviation, and percentage agreement). Qualitative data were analyzed through inductive thematic coding to identify recurrent categories related to clarity, coherence, usability, and improvement suggestions. All comments were anonymized to preserve confidentiality. Qualitative and quantitative findings were triangulated to enhance the robustness of the validation process.

*Supplementary materials, including all diagram versions, are available at: https://bit.ly/VCDiagrams

IV. RESULTS

A. Quantitative Findings

Overall, experts provided highly favorable evaluations across all dimensions of the *Velarde-Camaqui Diagram*. Table 1 presents descriptive statistics for each evaluated section.

TABLE I

Experts' Evaluation of the Velarde-Camaqui Diagram

Evaluated Criterion	Quality M ± SD (%)	Coherence M ± SD (%)	Relevance M ± SD (%)
Correlations & Associations	2.67 ± 0.50 (89%)	2.56 ± 0.53 (85%)	3.00 ± 0.00 (100%)
Types of Variables	2.78 ± 0.44 (93%)	2.89 ± 0.33 (96%)	2.89 ± 0.33 (96%)
Complete Diagram	2.67 ± 0.50 (89%)	2.67 ± 0.50 (89%)	2.78 ± 0.44 (93%)

Acceptance rates ranged from 85 to 100 percent, indicating strong expert consensus regarding the diagram's quality and educational usefulness. The **relevance** dimension achieved perfect agreement in the "correlations and associations" section, confirming the tool's pedagogical potential. The lowest value, 85 percent, appeared under **coherence**, suggesting minor refinements were required to improve logical transitions between decision nodes.

Aiken's V was estimated using the mean expert ratings on a three-point scale, where 1 represented the lowest score and 3 the highest score. The overall Aiken's V was .89, indicating strong content validity. Dimension-specific values ranged from .78 to 1.00, with the lowest value observed for the coherence of the correlations and associations section.

The consistency across categories demonstrates that the diagram satisfies the standards of content validity typically expected in educational tool development (Ramírez-Montoya & Tenorio-Sepúlveda, 2021). Experts agreed that its structure adequately represents the inferential decision process and that it can guide learners toward appropriate test choices even without advanced statistical background knowledge.

B. Qualitative Findings

Thematic analysis of expert comments revealed four main categories: *diagram clarity*, *information coherence*, *usability and educational application*, and *suggested improvements*. These insights provided detailed perspectives on the tool's strengths and the specific areas requiring refinement.

- Diagram clarity

Most experts agreed that the diagram was clear and conceptually accessible, particularly for individuals without a background in statistics. However, several experts noted minor issues related to visual density and terminology. Comments emphasized the need for consistent color schemes and minor linguistic corrections to enhance interpretability. Representative feedback included:

> "Spelling errors need to be corrected, but overall, it is clear and very useful."
> "Differentiating variables by color could improve readability and facilitate interpretation."

- Information coherence

Most experts highlighted that the diagram followed a logical flow from variable type to statistical test, demonstrating internal coherence. Nonetheless, some transitions between decision branches were described as slightly abrupt, particularly within the "correlations and associations" section. Experts suggested minor adjustments to strengthen logical connections:

> "Some transitions could be smoother to help users navigate the decision steps."
> "Labels should be reviewed to ensure conceptual precision between variable types and tests."

- Usability and educational application.

Experts emphasized that the diagram's structure provided pedagogical value beyond its immediate practical function. They recognized it as an accessible teaching tool capable of reducing anxiety among students and guiding decision-making during data analysis:

> "This diagram can be especially useful for learners with limited mathematical training. It provides structure and builds confidence."
> "It simplifies what is often an intimidating process for beginners."

Additionally, some experts proposed that the diagram could serve as a classroom resource or assessment tool in research methodology courses, offering visual reinforcement of inferential logic.

- Suggested improvements

Several experts recommended design enhancements, such as integrating color codes to differentiate between parametric and non-parametric tests, simplifying the visual density of the decision tree, and including illustrative examples of variable types. Others suggested linking the diagram to external resources—such as case studies or tutorials—to contextualize statistical applications:

> "Including references to normality tests or providing sample p-values would help users better understand test selection."
> "The structure is sound, but usability could improve with interactive features or hyperlinks."

These qualitative findings collectively confirmed the diagram's validity while also identifying practical refinements necessary for future iterations.

V. Discussion and Implications

The findings suggest that the Velarde-Camaqui Diagram functions as a structured visual scaffold that externalizes inferential decision-making processes. Rather than relying on memorization of statistical rules, users are guided through a sequential reasoning pathway, which may support the development of conceptual understanding in statistics.

From the perspective of Cognitive Load Theory [5], this structured representation may reduce extraneous cognitive load by organizing complex decision criteria into manageable steps. This aligns with prior research indicating that visual scaffolds can facilitate attention allocation and support procedural reasoning in complex tasks.

Unlike existing tools such as statsflowchart.co.uk [26], which provide direct recommendations without explicitly showing the decision pathway, the proposed diagram makes the inferential logic transparent. Similarly, while resources such as the UCLA Statistical Methods guide [27] present structured mappings between variables and tests, they function primarily as static reference tables rather than sequential decision-support systems. In contrast, the Velarde-Camaqui Diagram integrates a visual, step-by-step decision structure that supports both reasoning and learning.

Despite these contributions, the study has limitations. The expert panel was relatively small and predominantly composed of specialists in educational innovation, which may introduce bias toward pedagogical rather than statistical evaluation. Additionally, the study did not assess user performance or learning outcomes, which should be addressed in future research through student-based validation.

Finally, the diagram's multilingual availability (English, Spanish, Portuguese, French, Mandarin, and Russian) expands accessibility and supports broader adoption in diverse educational contexts.

VI. Conclusion and Future Work

This study achieved its main objective of validating the Velarde-Camaqui Diagram through expert judgment. The tool demonstrated high relevance and satisfactory clarity and coherence, positioning it as a valuable resource for teaching and research training in inferential statistics.

Beyond its validation, the diagram contributes by making the inferential decision process explicit through a structured visual pathway, supporting not only test selection but also conceptual understanding of statistical reasoning.

The validation process provides a foundation for the next stage: user validation with students and educators to examine usability, learning outcomes, and anxiety reduction. However, the findings should be interpreted considering the relatively small expert panel and the predominance of specialists in educational innovation.

An interactive digital version of the Velarde-Camaqui diagram is currently available at CallForScience.org (https://www.callforscience.org/en/statistics). This version, which integrates interactive decision pathways and tutorial resources, is currently undergoing validation to assess its usability and effectiveness in supporting statistical decision-making.

Overall, the Velarde-Camaqui Diagram represents a promising approach to improving accessible and transparent statistical decision-making in higher education.

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